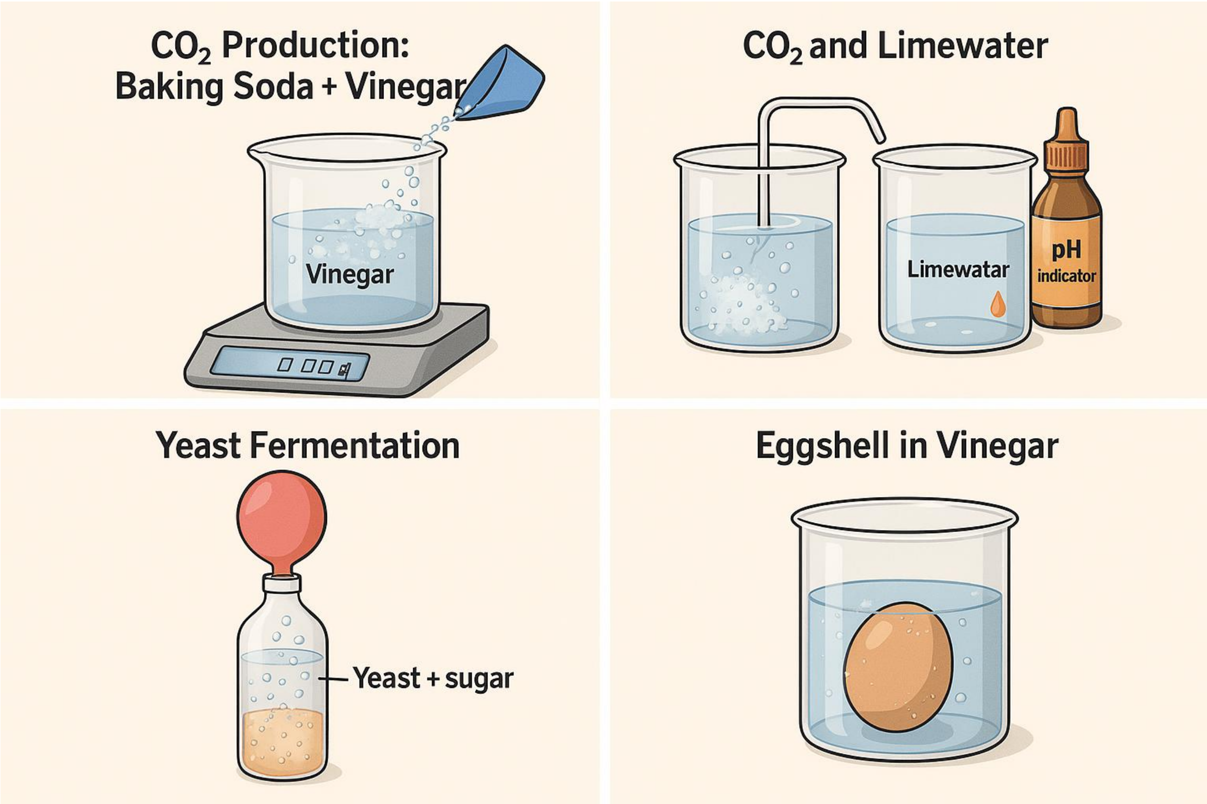
CO2 Introductory Demonstrations



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Status: research and proof of concept done, ready for external evaluation and feedback

Disclaimer: graphics in this document were generated using DALL-E as an initial example for later refinements with graphical designers after the core concept is evaluated and accepted.

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1. CO_2 Production: Baking Soda + Vinegar (Quantifying Mass Loss)

Goal: Observe and measure the production of CO_2 gas during a chemical reaction.

Procedure:

- Place a container with vinegar on a digital scale.
- Add a sealed container or folded paper with a known mass of baking soda.
- Zero the scale.
- Start the reaction and observe the decrease in mass.

Observation: The mass decreases as CO_2 gas escapes.

Reactants:

- Citric Acid ($C_6H_8O_7$)
- Baking Soda ($NaHCO_3$)

Products:

- Carbon Dioxide (CO_2)
- Water (H_2O)
- Sodium Citrate ($Na_3C_6H_5O_7$)

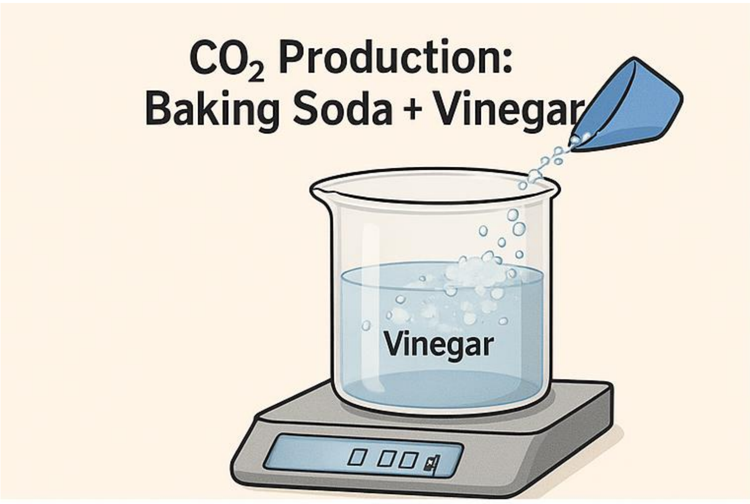
Reaction:

$$C_6H_8O_7 \; + \; 2\,NaHCO_3 \rightarrow 3\,CO_2 + 3\,H_2O + Na_3C_6H_5O_7$$

Extension:

- Record mass at intervals or final mass loss.
- Use stoichiometry to calculate expected CO_2 mass and compare to experimental results.

Visual Aid:



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Calculations: stoichiometric calculation

Question:

- How many grams of citric acid should I add to 5 grams of baking soda?
- How many grams of CO2 will be produced?

Step 1: Molar Masses

Compound	Formula	Molar Mass (g/mol)
Baking Soda	$NaHCO_3$	84.01
Citric Acid	$C_6H_8O_7$	192.12
Carbon Dioxide	CO_2	44.01

Step 2: Moles of Baking Soda (given)

$$n_{NaHCO_3} = \frac{5\ g}{84.01\ g/mol} \approx 0.0595\ mol$$

Step 3: Stoichiometry

From the balanced reaction:

- 1 mol citric acid reacts with **3 mol $NaHCO_3$**, so:

$$n_{citric\ acid} = \frac{1}{3} x 0.0595\ mol\ \approx 0.01983\ mol$$

Step 4: Mass of Citric Acid Needed

$$m_{citric\ acid} = n_{citric\ acid}\ x\ M_{citric\ acid} = 0.01983\ mol\ x\ 192.12 \frac{g}{mol} \approx 3.81\ g$$

Step 5: CO_2 Produced

From the balanced reaction:

- The reaction produces **3 mol CO_2 per 3 mol $NaHCO_3$**, so:

$$n_{CO_2} = 0.0595\ mol$$

$$m_{CO_2} = 0.0595\ mol\ x\ 44.01 \frac{g}{mol} \approx 2.62\ g$$

Summary:

- You need **3.81 g of citric acid** to react with **5 g of baking soda**.
- You will produce approximately **2.62 g of CO_2** gas.

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Calculations: air composition

Question:

- What is the volume of CO2 released?
- What will be the CO2 concentration in sealed box?

Solution:

Given:

- **CO_2 mass produced**: ~2.62 g (from earlier calculation)
- **Box dimensions**: 45cm x 34 cm x 18 cm (box used in our test)
- **Molar mass of CO_2**: 44.01 g/mol
- **Moles of CO_2 produced**:

$$\frac{2.62\ g}{44.01\,\frac{g}{mol}} \approx 0.0595\ mol$$

- **Molar volume of gas at room temp (25 °C, 1 atm)**: ~24.0 L/mol

Step 1: Box Volume

$$45\ cm\ x\ 34\ cm\ x\ 18\ cm = 27.540\ cm^3 = 27.54\ l$$

Step 2: Volume of CO_2 produced

$$V_{CO_2} = 0.0595\ mol\ x\ 24.0\,\frac{l}{mol} \approx 1.43\ l$$

Step 3: CO_2 Concentration in the Box

$$Concentration = \frac{1.43\ l}{27.54\ l} \approx 0.0519 \approx 5.2\% = 52\ 000\ ppm$$

Conclusion:

- The reaction would release **~1.43 L** of CO_2
- In a sealed 45×34×18 cm box, this would result in a **~5.2% concentration** of CO_2 by volume

This level is **well above atmospheric CO_2 (0.04%)** and high enough to impact sensors or potentially displace oxygen in a small sealed environment. This shows how even simple reactions can change local environments, like a mini greenhouse.

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Calculations: pressure change

Question: if there is CO2 release in a closed container, would the pressure change?

Assumptions:

- **The box is rigid and sealed** (no gas escapes).
- **Room temperature (25°C) and small pressure change**, so ideal gas law applies:

$$PV = nRT$$

If **volume (V)** and **temperature (T)** are constant, then $P \sim n$

Solution:

1. Volume of the box: $V = 27.54\ L$ (calculated earlier)

2. Initial number of moles (before reaction): Assume 1 atm and 25°C:

$$n_{before} = \frac{PV}{RT} = \frac{1x27.54}{0.0821x298} \approx 1.12\ mol$$

3. CO_2 added from reaction: $n_{CO_2} = 0.0595\ mol$ (calculated earlier)

4. Final number of moles: $n_{after} = n_{before} + n_{CO_2} = 1.12\ mol + 0.0595\ mol = 1.1795\ mol$

5. New pressure: $\frac{p_{after}}{1\ atm} = \frac{1.1795\ mol}{1.12\ mol} \approx 1.053\ atm \approx 106.6\ kPa$

Result:

- **Initial pressure:** 101.3 kPa (1 atm)
- **After reaction: 106.6 kPa**
- **Increase:** ~5.3%

Conclusion:

- The pressure in the sealed box increases by **about 5.3%**, due to CO_2 gas production.
- This is enough to register on a sensitive pressure sensor (like a barometric sensor).
- In a more flexible container, this pressure might cause slight expansion or leakage.
- In rigid container greater amount of reagents can cause explosion!

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2. CO_2 and Limewater (Gas Detection + pH Indicator)

Goal: Detect CO_2 and observe its effect on pH.

Procedure:

- Prepare limewater in two beakers.
- In one, bubble CO_2 from vinegar + baking soda reaction.
- In the other, exhale through a straw.
- Add a few drops of pH indicator (e.g. universal indicator or bromothymol blue).

Observation: Limewater turns cloudy, indicator shifts toward acidic color.

Reactants:

- Calcium Hydroxide (limewater, $Ca(OH)_2$)
- Carbon Dioxide (CO_2)

Products:

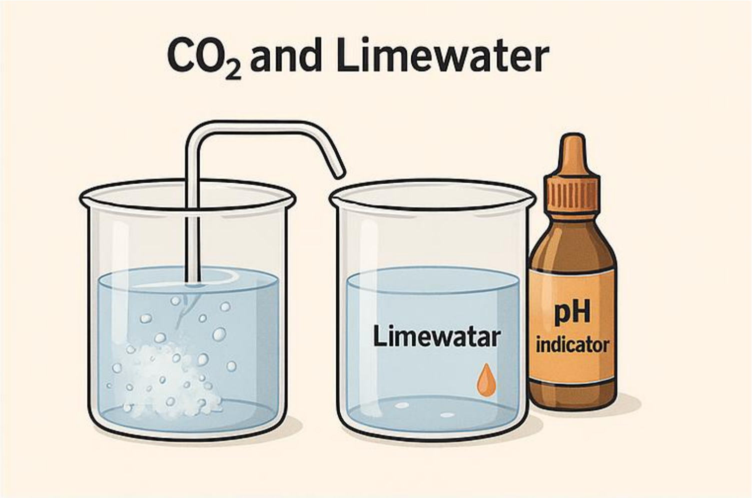
- Calcium Carbonate precipitate ($CaCO_3$ – cloudy)
- Water (H_2O)

Reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow + H_2O$$

Explanation: Formation of carbonic acid lowers pH, indicating CO_2 presence and acidity.

Visual Aid:



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3. Yeast Fermentation (Biological CO_2 Source)

Goal: Show biological CO_2 production and measure gas output.

Procedure:

- Mix yeast, sugar, and warm water in a bottle.
- Attach balloon or use a syringe/tubing setup to collect gas.
- Measure balloon size or gas volume in a graduated cylinder (displacement method).

Reactants:

- Glucose ($C_6H_{12}O_6$)

Products:

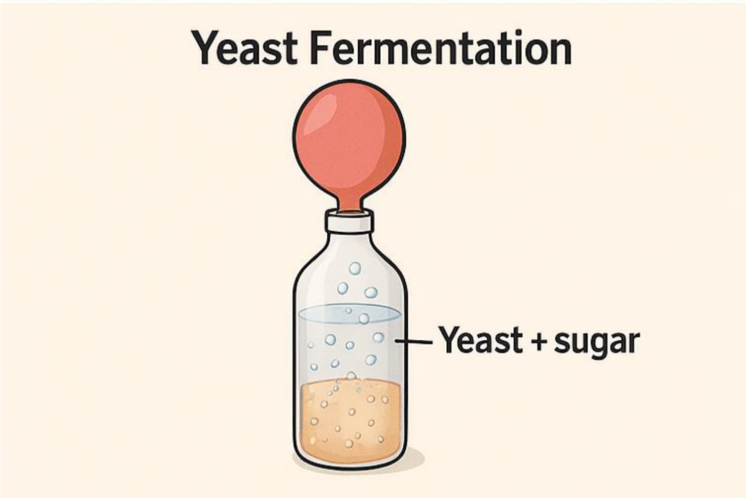
- Carbon Dioxide (CO_2)
- Ethanol (C_2H_5OH)

Reaction:

$$C_6H_{12}O_6 \xrightarrow{yeast} 2\,CO_2 + 2\,C_2H_5OH$$

Extension: Compare sugar types or temperatures to study effect on CO_2 production.

Visual Aid:



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4. Acid-Base Reaction: Eggshell in Vinegar (CO_2 + Shell Dissolution)

Goal: Observe CO_2 production and acid reaction with calcium carbonate.

Procedure:

- Place an egg in vinegar and observe over 1–2 days.
- Note bubble formation (CO_2).
- Shell will dissolve; membrane remains.

Reactants:

- Acetic Acid (vinegar,)
- Calcium Carbonate ($CaCO_3$ in eggshell)

Products:

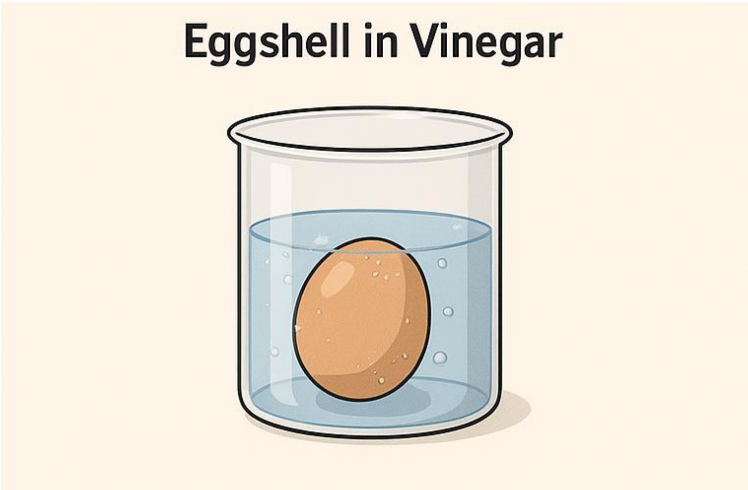
- Calcium Acetate ($Ca(CH_3COO)_2$)
- Water (H_2O)
- Carbon Dioxide (CO_2)

$$2\,CH_3COOH + CaCO_3 \rightarrow Ca(CH_3COO)_2 + H_2O + CO_2$$

Extension:

- Use a pH probe or indicator to monitor acid strength over time.
- Relate to carbonic acid's role in ocean acidification and shell dissolution in marine organisms.

Visual Aid:



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5. Yeast and Hydrogen Peroxide (O_2 Production via Catalase)

Goal: Demonstrate the enzymatic breakdown of hydrogen peroxide by catalase in yeast, releasing oxygen gas.

Materials:

- Active dry yeast
- Warm water
- 3–6% hydrogen peroxide (standard pharmacy strength)
- Clear container (graduated cylinder or beaker)
- Optional: dish soap and food coloring

Basic Procedure:

1. Dissolve yeast in warm water (activates enzymes).
2. In a beaker or cylinder, add a small amount of dish soap and food coloring (optional but helps visualize bubbles).
3. Pour in hydrogen peroxide.
4. Add the yeast solution.

Observation: Rapid bubbling/frothing as oxygen gas is produced.

Explanation: Yeast contains **catalase**, an enzyme that breaks down hydrogen peroxide into water and oxygen. The soap traps oxygen gas, forming foam.

Reactants:

- Hydrogen Peroxide (H_2O_2)

Products:

- Water (H_2O)
- Oxygen (O_2)

Reaction:

$$2\,H_2O_2 \xrightarrow{catalase} 2\,H_2O + O_2$$

Extension Ideas for High School:

- **Measure reaction rate**: Collect gas over water to measure oxygen volume.
- **Compare variables**: Different H_2O_2 concentrations, temperatures, or types of cells (e.g., liver vs yeast).
- **Link to biology**: Discuss catalase's protective role in cells.

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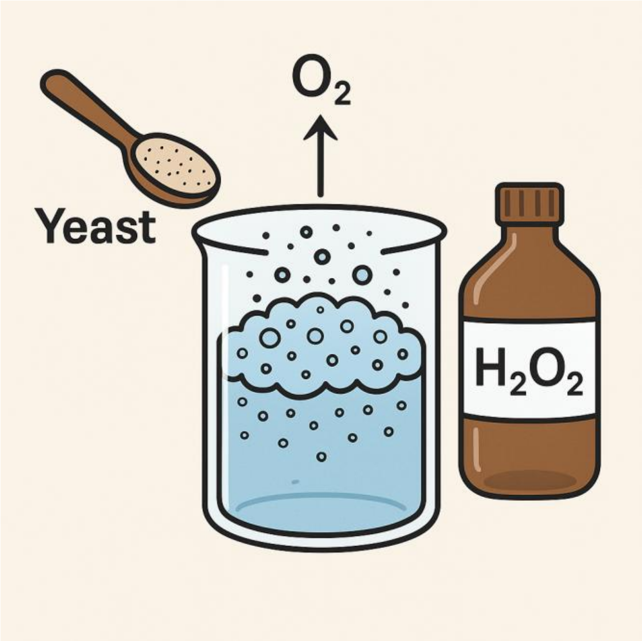
Visual Aid:



6. Human Respiration and Gas Composition

Goal:

Demonstrate how human breathing alters the concentration of **oxygen and carbon dioxide** in a closed system (like a balloon or sealed box).

Option A: Breathing into a Balloon

Option B: Breathing into a Sealed Box via Straw or Tube

Setup:

- CO_2/O_2 sensor inside a large balloon or sealed box
- User exhales into it, then breathes in/out a few times using only air from the balloon/box

What happens:

- **O_2 decreases** with each breath (lungs absorb oxygen).
- **CO_2 increases** (lungs release CO_2).
- Relative humidity also rises

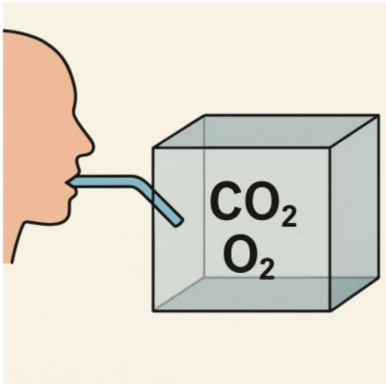
Expected values:

- Ambient air: ~21% O_2, ~0.04% CO_2
- Exhaled air: ~16% O_2, ~4% CO_2
- After multiple breaths: O_2 drops below 16%, CO_2 may exceed 5%

Extensions:

- **Graph CO_2 and O_2 changes over time.**
- **Compare two setups:** balloon vs box — how fast do gases change?
- **Discuss safety:** At what point does air become unbreathable?

Visual Aid:



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7. Photosynthesis with Elodea (Moczarka)

Goal: Demonstrate that aquatic plants absorb CO_2 and produce O_2 through photosynthesis.

Materials:

- A few sprigs of *Elodea* (moczarka)
- Beaker or test tube
- Water (preferably dechlorinated)
- Baking soda ($NaHCO_3$) – as a CO_2 source
- Light source (lamp or sunlight)
- Funnel and small test tube (optional, for gas collection)

Procedure:

1. Fill a beaker with water and add a pinch of baking soda to increase dissolved CO_2.
2. Place Elodea in the beaker, cut side up.
3. Expose it to a strong light.
4. Observe the formation of **bubbles** on or around the plant.
5. (Optional) Place a funnel over the plant and invert a water-filled test tube over it to collect oxygen.

Observation:

- Bubbles (O_2) form during photosynthesis.
- The rate increases with more light or CO_2.

Chemical Reaction:

$$6\ CO_2 + 6\ H_2O \xrightarrow{ligh\ (hv)} C_6H_{12}O_6 + H_2O$$

Extensions:

- Count bubbles per minute to measure photosynthesis rate.
- Change variables: light intensity, temperature, CO_2 levels.
- Use a CO_2 sensor in the water to show depletion.

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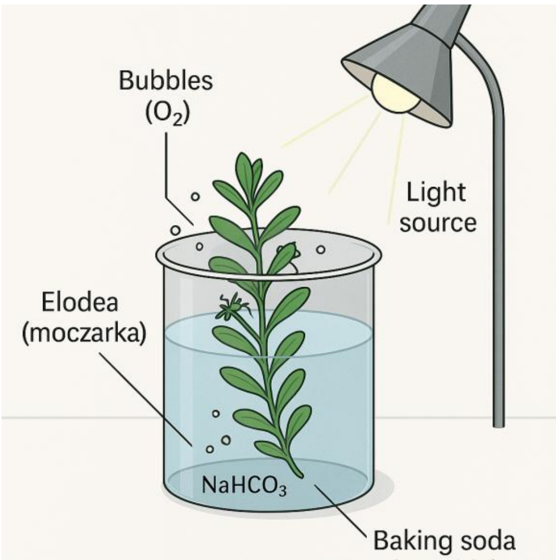
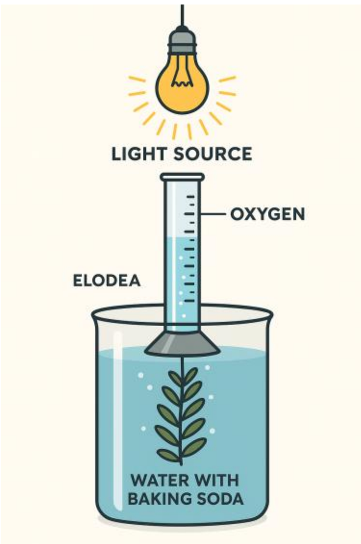
Visual Aid:



Visual Aid of extended version with oxygen collection:

Setup:

1. Fill the measuring cylinder completely with **bicarbonate water** (to ensure CO_2 availability).
2. Place **Elodea sprigs under a funnel**, cut ends upward.
3. Invert the water-filled measuring cylinder over the funnel spout (no air bubbles inside).
4. Place the setup under a light source.
5. Wait and observe the **oxygen collecting in the cylinder**.



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